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CLEAN VERSION



# EXPOSURE METHOD, MASK FABRICATION METHOD, FABRICATION METHOD OF SEMICONDUCTOR DEVICE, AND EXPOSURE APPARATUS

## CROSS REFERENCE TO RELATED APPLICATION

This application claims priority from Japanese Priority Document No. 2002-189086, filed on Jun. 28, 2002 with the Japanese Patent Office, which document is hereby incorporated by reference.

## BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an exposure method used in a lithography process for forming a circuit pattern of a semiconductor device, a mask fabrication method of an exposure mask used in this lithography process, a fabrication method of a semiconductor device including this lithography process, and an exposure apparatus.

2. Description of the Related Art

[0002] In a lithography process that is one of the processes for fabricating a semiconductor device, a wave-length of a light source in an exposure apparatus tends to be shorter along with the miniaturization of the forming pattern. For example, the light source has been changed from an i-ray (wave-length = 365 nm) to a KrF Excimer (wave-length = 248 nm), to an ArF Excimer (wave-length = 93 nm), and to an F2 (wave-length = 53 nm). This means that in order to improve principally the resolution, the numerical aperture (NA) of a projection optical system is increased and the wave-length of the exposure light is shortened. Generally, it is well-known that the resolution determined by the wave-length of an exposure light is expressed by the Rayleigh's formula as $w = K1 \times (\lambda / NA)$, wherein w is the resolution of a pattern, NA is the numerical aperture of the projection optical system, and $\lambda$ is the wave-length of the exposure light. Further, K1 is a positive constant less than 1 determined by the resist and the process used in the exposure process.

[0003] Further, it has recently been proposed to use a so-called Extreme Ultra Violet ray (EUV), such as a light of a soft X-ray region having a wave-length of 5 to 15 nm, as the exposure light in order to cope with further miniaturization of a pattern. When the

EUV ray is employed, a resolution w = 43 nm is obtained from the above-mentioned Rayleigh's formula, provided that K1 = 0.8, NA= 0.25, and the wave-length of the EUV ray as the exposure light is 13.5 nm. Then, it becomes possible to carry out the process of the pattern that is matching with a design rule for 50 nm pattern width. To that end, the EUV exposure technology is expected to be a possible candidate as a future exposure technology.

[0004] In this case, regarding the EUV ray, there is not any material or substance that transmits but does not absorb the EUV ray, so it is impossible for the EUV ray to configure a light transmission type projection optical system that is widely applied in a conventional lithography process. Accordingly, it is necessary to configure a reflection type projection optical system (including a reflective mask and a reflection type optical system for reflecting a light) in the case of using the EUV ray.

[0005] Fig. 3 is a schematic diagram designating one example of an exposure apparatus having a reflection type projection optical system. The exposure apparatus in Fig. 3 comprises an optical source 1 for the EUV ray, a reflective mask 2 and a reflection type optical system 3 (plural reflection mirrors, for example), a mask holder 4 for holding the reflective mask 2, a movable reticle stage 5, a wafer holder 6, and a movable wafer stage 7. A wafer 8, as an object to be exposed is to be held on the movable wafer stage 7 by way of the wafer holder 6.

As the optical source 1 for the EUV ray, a laser plasma system is pointed out, wherein a high power laser light, such as the Excimer laser or the like, is focused and irradiated on the EUV ray radiating material, such as rare gas, spouting from a nozzle (not shown) and generates the EUV ray upon transiting to a low potential condition, so that the material is excited to be in plasma state. And, the EUV ray irradiated from the light source 1 passes through the reflection type optical system 3, and thereby the pattern (the mask pattern) formed on the reflection plane of the reflective mask 2 is projected on the wafer 8 as an LSI pattern (circuit pattern that is necessary for configuration of the semiconductor device). In this case, the illuminated area on the reflective mask 2 is formed in a ring shape, and further, a scanning exposure system is employed, wherein the pattern on the reflective mask 2 is projected sequentially on the wafer 8 by relatively scanning the reflective mask 2 and the wafer 8 relative to the reflection type optical system 3.

[0006] Fig. 4 is a perspective view designating an exemplified configuration of the reflective mask 2 used in the exposure apparatus. As shown in this figure, it is known that such a mask is equipped with a mask blank 2a for reflecting the EUV ray and an EUV-ray absorption film formed so as to cover the reflection plane of the mask blank 2a. The mask blank 2a has a multi-layered film structure formed by alternately stacking a Mo (Molybdenum) film and an Si (Silicon) film, and the repetition number of the stacks is usually 40. By the multi-layered film structure as described above, the mask blank 2a reflects the EUV ray having 13.5 nm in wave-length at a reflectivity of approximately 70 %. Further, by covering the reflection plane of the mask blank 2a with the absorption film 2b having a corresponding pattern thereof, the reflection of the EUV ray is carried out selectively. In this case, if the reflection material, such as multi-layered film, carried out the patterning to the absorption film blank, a recovery upon failure is impossible; but if the patterning is carried out by providing such absorption film 2b, it becomes possible to try again and also easy to repair the pattern, so that it is preferable to cover the mask blank 2a with the absorption film 2b.

[0007] In case of using such reflective mask 2, the light reflected at the reflection plane has to be introduced to the reflection type optical system 3 without mutually interfering with the incident light to the reflection plane. Accordingly, the incident light to the reflective mask 2 has to be a skewed incident light having an incident angle θ relative to a normal line of the reflection plane. The incident angle θ of the incident light is determined by the NA of illumination (hereinafter referred to as an NAill) at the reflection plane, and this is determined by the NA at the wafer surface of a reflective type projection optical system and the magnification of projection based on the desired resolution. For example, provided that the magnification of projection is 4 times the system taking over the magnification of projection of a conventional exposure apparatus, the incident angle θ of the incident light to the reflective mask 2 becomes around 4 degrees when the level of the NA = 0.2 to 0.3 determined by the desired resolution.

[0008] However, in case of the skewed incidence as above described, the pattern width projected on the wafer 8 fluctuates depending on the direction of the mask pattern on the reflective mask 2 relative to the projection vector of the incident light.

[0009] In this case, if the mask pattern is for projecting of the LSI pattern, for example, the direction of the mask pattern is divided by whether the mask pattern is parallel or

perpendicular relative to the direction of the projection vector of the EUV ray. In other words, the mask pattern for projection of the LSI pattern is normally able to be divided into pattern forming elements having sides parallel to the direction of the projection vector and pattern forming elements having sides orthogonal to the direction of the projection vector. Accordingly, each pattern forming element comprising the mask pattern is defined as described hereinafter in this text.

[0010] Fig. 5 is a schematic diagram for explaining the direction of the mask pattern. As shown in the figure, the mask pattern formed on the reflective mask 2 is scanned in the Y direction in the figure as the movable reticle stage 5 moves (shown in Fig. 3), and thereby, the mask pattern is projected on the wafer 8. The incident angle $\theta$ (4 degrees, for example) of the EUV ray incoming askew at this time is the angle around the X axis in the figure. Accordingly, the pattern forming elements extending in the direction parallel to the scanning direction of the mask pattern, namely the pattern forming elements having sides parallel to the direction of the projection vector, are defined as a V-line (Vertical-line). On the contrary, the pattern forming elements extending in the direction vertical to the scanning direction of the mask pattern, namely the pattern forming elements having sides orthogonal the direction of the projection vector, are defined as an H-line (Horizontal-line).

[0011] Fig. 6 is a schematic diagram for designating one specific example obtained by simulating the difference of the pattern width of the V-line and the H-line after pattern projection when the EUV ray incidents askew. Generally, in the case of strictly simulating the difference of the pattern width of the V-line and the H-line, it is necessary to introduce a three-dimensional electromagnetic field simulation on the basis of the thickness of the absorption film 2b (Fig. 4) on the reflective mask 2; but, in the figure, it is approached by the case where the EUV ray incidents on a two-dimensional binary mask, provided that the thickness of the absorption film 2b is zero. In the result of the simulation depicted in Fig. 6, the projected line width of a line and a space of every V-line and the H-line on the wafer 8 is calculated under the condition where the wave-length of the EUV ray = 13.5 nm, the NA = 0.25, the $\sigma = 0.70$, the incident angle on the mask = 4 degrees (around X axis), the magnification of projection is 4, and the pattern width of the line and the space on the wafer = 50 nm. According to the simulation result, it is recognized that there is a the line width difference of around 4 nm

between the V-line and the H-line in the range of the focus range of ± 0.1 μm. Further, it is recognized that the fluctuation of the V-line and the H-line within the focus range is around 2 times.

[0012] As described above, when the EUV ray incidents askew on the reflective mask 2, the width of the line pattern projected on the wafer 8 is fluctuated depending on the direction of the mask pattern relative to the projection vector, and, as the result, it is likely to cause an adverse effect on the resolution of the projected image. However, various technologies are conventionally proposed regarding the correction for removing the difference between the width of the projected V-line and H-line patterns; but the technology for improving the margin difference of the resolution depending on the incident angle of the EUV ray upon exposure process which causes fluctuation in the width of the projected V and H line patterns is not particularly proposed. Further, the width of the projected pattern also depends on the repetition rate or the crude density of the pattern on the reflective mask 2 ( hereinafter, this is called as an OPE (Optical Proximity Effect) characteristic), and this OPE characteristic also fluctuates depending on the incident angle of the EUV ray.

## SUMMARY OF THE INVENTION

[0013] According to the present invention, it is so arranged as not to cause a difference of the pattern width between the V-line and the H-line, namely the influence caused by the direction of the mask pattern relative to the projection vector, without depending on the correction of the mask pattern, for example. Namely, the present invention proposes an exposure method capable of improving the margin difference of the resolution in the projected image without introducing misalignment or distortion (distortion in pattern width) of the projected image, a mask fabrication method, and a fabrication method of a semiconductor device.

[0014] This invention is presented to attain the above-mentioned improvement. Namely, the present invention is an exposure method for projection of a desired pattern on an object to be exposed using a reflective mask for an exposure light, wherein pattern forming elements of a mask pattern corresponding to the above-mentioned desired pattern are divided with regard to respective direction relative to the projection vector of the exposure light and a set of reflective mask patterns with each mask pattern

having only the pattern forming elements of the same direction is provided. Then, the projection of the pattern on the object to be exposed is carried out sequentially by the irradiation and reflection of the exposure light with regard to the reflective mask of respective direction. In this case, when the one reflective mask is changed to the other reflective mask, the other reflective mask and the object to be exposed are rotated relative to the projection vector so that the angle of the pattern forming elements of the other reflective mask and the projection vector becomes equal to the angle of the pattern forming elements of the one reflective mask and the projection vector.

[0015] Further, the present invention is a mask fabrication method that is presented to attain the above-mentioned improvement. Namely, the present invention is a fabrication method for fabricating a reflective mask to be used for projecting a desired pattern on an object to be exposed by reflecting an exposure light, wherein pattern forming elements of a mask pattern corresponding to the above-mentioned desired pattern are divided with regard to the respective direction relative to their projection vector , and a set of reflective mask patterns with each having only the pattern forming elements of the same direction is provided. With regard to respective reflective mask, each reflective mask and the above-mentioned object to be exposed are rotated relative to the projection vector so that the angle of each of reflective mask and the projection vector is always the same.

[0016] Further, the present invention is a fabrication method of a semiconductor device that is presented to attain the above-mentioned improvement. Namely, the present invention is a fabrication method of a semiconductor device including a lithography process for projection of a desired pattern on an object to be exposed by using a reflective mask for an exposure light, wherein pattern forming elements of a mask pattern corresponding to the above-mentioned desired pattern are divided with regard to the respective direction relative to the projection vector of the exposure light and a set of reflective mask patterns with each mask pattern having only the pattern forming elements of the same direction is provided. Then, the projection of the pattern on the object to be exposed is carried out sequentially by the irradiation and reflection of the exposure light with regard to the reflective mask of respective direction. In this case, when the one reflective mask is changed to the other reflective mask, the other reflective mask and the object to be exposed are rotated relative to the projection vector

so that the angle of the pattern forming elements of the other reflective mask and the projection vector becomes equal to the angle of the pattern forming elements of the one reflective mask and the projection vector.

[0017] According to the exposure method, the mask fabrication method, and the fabrication method of a semiconductor device as above-mentioned procedures, the mask patterns corresponding a desired pattern to be formed on an object to be exposed are divided into V-line pattern forming elements and H-line pattern forming elements with regard to respective direction, and a pair of reflective mask patterns with each mask pattern corresponding to respective direction is provided. Then, when the one reflective mask is changed to the other reflective mask, the other reflective mask and the object to be exposed are rotated. Thereby, the angle of the pattern forming elements of the respective mask and the projection vector always becomes the same. Accordingly, even in the case where the exposure light incidents askew on the reflective mask, there is no possibility of causing a difference in the width of the projected pattern depending on the angle between the pattern forming elements and the projection vector.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 shows a brief overview of an exposure method according to the present invention, wherein (a), (b), and (c) show procedures of the exposure method;

Fig. 2 is a flowchart designating a flow of procedures of a mask fabrication method according to the present invention;

Fig. 3 is a schematic diagram designating one embodiment of an exposure apparatus having a reflection type projection optical system according to the present invention;

Fig. 4 is a perspective view showing one configured example of a reflective mask used in the exposure apparatus in Fig. 3;

Fig. 5 is a schematic diagram for explaining a direction of a mask; and

Fig. 6 is a schematic diagram for designating one specific example obtained by simulating the difference of the pattern width of the V-line and the H-line after projection when the exposure light incidents askew.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] Hereinafter, an exposure method, a mask fabrication method, a fabrication method of a semiconductor device, and an exposure apparatus according to the present invention will be described with reference to the drawings. However, only the difference relative to a conventional apparatus is explained, and explanations of the configuration of an exposure apparatus that is similar to a conventional one (Fig. 3) and the configuration of a reflective mask itself (Fig. 4) are omitted here.

[0019] Fig. 1 shows a brief overview of an exposure method according to the present invention. In a lithography process that is one of the processes for fabricating a semiconductor device, the exposure method explained here is applied to the projection of an LSI pattern necessary for configuring the semiconductor device on a wafer as an object to be exposed. In more detail, this exposure method is applied, while using a reflective mask for an EUV ray (wave-length = 13.5 nm, for example) to project a mask pattern formed on the refection type mask on the wafer, thereby forming the LSI pattern on the wafer. The exposure light may be one of a charged particle beam, an X-ray, an Extreme Ultra Violet ray, an Ultra Violet ray, and a visible light, but the explanation in this text is done with the EUV ray as one of the examples for exposure light.

[0020] The mask pattern at this time includes pattern forming elements 11a of a V-line extending in a parallel direction relative to a direction of a projection vector of a skewed incident EUV ray, as shown by (a) in Fig. 1, and pattern forming elements 11b of a H-line extending in a vertical direction relative to the projection vector. In order to project such a mask pattern on a wafer, a reflective mask is prepared or formed by the procedures described below.

[0021] Fig. 2 is a flowchart designating a flow of procedures of a mask fabrication method according to the present invention. As shown in the figure, when forming the pattern of the reflective mask in the present embodiment, input design data (data for whole pattern) are acquired for the mask pattern corresponding to the LSI pattern to be formed on a wafer in a step S101. As the input design data, CAD (Computer Aided Design) data correspond to them, for example. Then, the input design data are divided into V-line data corresponding to the pattern forming elements 11a of the V-line and H-line data corresponding to the pattern forming elements 11b of the H-line.

[0022] To be more specific, by erasing size data of over-size and under-size of only for an X direction in a step 102, the graphic data only for the X direction are extracted in a step S103. In this case, a coordinate space on the input design data is consistent with a coordinate space upon exposure. Accordingly, the graphic data extending in the X direction correspond to the H-line data, and the graphic data extending in the Y direction (that is, the operating direction of the exposure apparatus) correspond to the V-line data. After the graphic data only for the X direction are extracted, then the graphic data only for the X direction are subtracted from the input design data in a step S104, and the rest of the graphic data are extracted therefrom in a step S105. The rest of the graphic data are to correspond to the graphic data extending in the Y direction, namely, the V-line data. As described above, in the case of forming such reflective mask, it is necessary to divide the input design data for the mask pattern into the V-line data and the H-line data relative to respective direction with regard to the direction of the projection vector of the EUV ray.

[0023] Then, based on the divided V-line data and H-line data, a V-line mask 12a having a mask pattern consisting of the pattern forming elements 11a only for the V-line and an H-line mask 12b having a mask pattern consisting of the pattern forming elements 11b only for the H-line are formed respectively. Thus, the reflective masks 12a and 12b for respective direction are prepared.

[0024] In this case, the V-line mask 12a and the H-line mask 12b may be formed with a conventional method, so that an explanation thereof is omitted here. Further, regarding the division of the input design data into the divided V-line data and H-line data, it is not necessary to carry out the division by the above-mentioned procedures, and other already known graphic processing technology may be applied.

[0025] After the V-line mask 12a and the H-line mask 12b are prepared, the mask pattern is at first projected on the wafer 8 using one of the two masks. Namely, the EUV ray is irradiated on one of the V-line mask 12a or the H-line mask 12b and forms by arriving reflection light on the wafer 8 either the mask pattern consisting of the pattern forming elements 11a only for the V-line or an H-line mask 12b having the mask pattern consisting of the pattern forming elements 11b only for the H-line.

[0026] After one of the pattern images is projected, the mask pattern of the other reflective mask 12a or 12b is projected on the wafer 8. For example, if the process for

the exposure and projection is by using the V-line mask 12a, then the process for the exposure and projection by using the H-line mask 12b is carried out. In this case, the relative position of the H-line mask 12b that corresponds to the other reflective mask is rotated approximately by 90 degrees relative to the projection vector of the EUV ray. Further, as shown in by (c) in Fig. 1, the relative position of the wafer 8 on which the pattern is projected also is rotated approximately by 90 degrees relative to the projection vector of the EUV ray.

[0027] Thereby, even if the irradiating object of the EUV ray is changed to the other reflective mask, namely to the H-line mask 12b, the angle of the pattern forming elements 11b of the H-line mask 12b and the projection vector of the EUV ray becomes equal to the angle of the pattern forming elements 11a of the V-line mask 12b and the projection vector of the EUV ray, wherein the exposure using the V-line mask 12b is finished in advance. Further, because the wafer 8 also is rotated by approximately 90 degrees, the projected image of the desired pattern is to be correctly formed on the wafer 8, even the H-line mask 12b is rotated by approximately 90 degrees when the mask is changed to the H-line mask 12b.

[0028] As explained above, according to the present embodiment, the V-line mask 12a and the H-line mask 12b are provided or formed by dividing a mask pattern regarding respective direction relative to the projection vector of the EUV ray. Then, the exposure and the projection by using respectively reflective masks12a and 12b are carried out sequentially. In this case, when the reflective masks 12a and 12b are changed from the one to the other, doubled exposures are to be carried out by rotating the other mask and the wafer 8. In the case where the EUV ray is coming askew to respective reflective masks 12a and 12b, the angle of the projection vector of the EUV ray and the respective pattern forming elements 11a and 11b of the respective reflective mask 12a and 12b is always the same. Accordingly, no adverse effect due to the angle of the projection vector and the pattern forming elements 11a and 11b occurs principally without depending on the correction of the mask pattern, so that it is very much possible to avoid the occurrence of misalignment or distortion (distortion of pattern width) of the projected image. As a result, it is able to prevent the adverse effect of the direction of the mask pattern to the resolution of the projected image.

[0029] Particularly, if, as explained in the above-mentioned embodiment, the exposure

process is carried out twice by using the V-line mask 12a and the H-line mask 12b in this order, and the extending directions of the pattern forming elements 11 a and 11b are aligned in the direction of the projection vector of the EUV ray, it becomes very effective in the case of improving the resolution of the projected image on the wafer 8 even when the EUV ray is incoming askew.

[0030] Further, in the case of forming a LSI pattern on the wafer 8, the pattern comprises forming elements mainly extending in the directions of the V-line and the H-line, so that, as explained in the above-mentioned embodiment, it is effective to expose twice using the V-line mask 11a and the H-line mask 11b from the perspective of the resolution, the efficiency of the process and the like; but the present invention is not limited to expose twice using the V-line mask 11a and the H-line mask 11b. For example, if sequential exposures and relative positional rotations are done with regard to respective direction by providing respective reflective masks with regard to respective direction regarding the projection vector of the EUV ray, the exposure process may be carried out three times or more. That is, the above-mentioned embodiment is one of the embodiments of the present invention, and the scope of the present invention is not limited to this. Further, the exposure light of the present invention is not limited to the EUV ray, and the exposure light may be one of a charged particle beam, an X-ray, an Extreme Ultra Violet ray, an Ultra Violet ray, and a visible light.